AD-753 577

A REVIEW OF HIGH-GLIDE PERSONNEL PARACHUTES AND THEIR POTENTIAL FOR MILITARY AIRBORNE OPERATIONS

Stanley J. Shute, Jr.

Army Natick Laboratories
Natick, Massachusetts

August 1971

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

TECHNICAL REPORT
72-14-AD

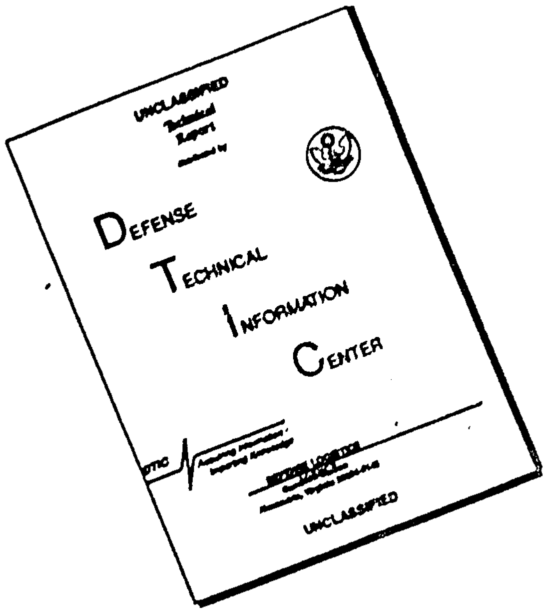
A REVIEW OF HIGH-GLIDE PERSONNEL PARACHUTES AND THEIR POTENTIAL FOR MILITARY AIRBORNE OPERATIONS

by
Stanley J. Shute, Jr.

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

36
R

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

Approved for public release;
distribution unlimited

AD_______________

TECHNICAL REPORT
72-14-AD

A REVIEW OF HIGH-GLIDE PERSONNEL PARACHUTES

and

THEIR POTENTIAL FOR MILITARY AIRBORNE OPERATIONS

by

Stanley J. Shute, Jr.

August 1971

Airdrop Engineering Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts 01760

FOREWORD

Although there has been no documented Army Requirement, the use of high-glide personnel parachutes has been considered to be applicable for certain types of military airborne operations. Some of the possible military personnel delivery applications are reviewed along with performance characteristics and considerations of the better known high-glide parachute designs.

This study was conducted under Department of the Army Project No. 1F162203AA33-03, Exploratory Development of Airdrop Systems.

TABLE OF CONTENTS

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U. S. Army Natick Laboratories Natick, Massachusetts 01760	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

A REVIEW OF HIGH-GLIDE PERSONNEL PARACHUTES AND THEIR POTENTIAL FOR MILITARY AIRBORNE OPERATIONS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Stanley J. Shute, Jr.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 71	~~28~~ 36	5

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 1F162203AA33-03	TR-72-14-AD
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	US Army Natick Laboratories Natick, Mass. 01760

13. ABSTRACT

The successful accomplishment of certain types of military airborne operations would be enhanced if the parachutists had the capability to glide and maneuver across relatively large distances while descending to their intended landing area. Many jumps by sport parachutists and military exhibition teams have demonstrated the feasibility of maneuverable, high-glide personnel parachutes. The performance characteristics of the best known high-glide parachute designs are reviewed along with their possible application to military personnel airdrop operations. Although sport and exhibition jumps are being made as an everyday occurrence, many problems of a theoretical and practical nature remain to be solved for the successful application of high-glide parachutes to the more demanding requirements that might be necessary for military operations involving paratroopers.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified

Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Reviewing	8					
Parachutes	9					
Airborne Operations	4					
Military Operations	4					
High-glide Parachutes	9					
Maneuverability	8					

ib

Security Classification

LIST OF FIGURES

INTRODUCTION

Purpose

The satisfactory accomplishment of certain types of military airborne operations would be enhanced by the ability of the parachuting personnel to traverse and maneuver across relatively large horizontal distances while descending from medium and high altitudes. It would also be beneficial for them to have the capability of penetrating or moving against the prevailing wind. Within the last twenty years, parachutes have evolved from straight drag producing devices to those that glide, i.e., they have canopies that produce not only drag but also lift. It is the purpose of this report to examine the possible military personnel airdrop applications for a maneuverable, high-glide ratio parachute and to discuss the performance of current designs. The parachutes included in this report have glide ratios of two to one or better and are arbitrarily categorized as high-glide parachutes.

MILITARY POTENTIAL

The high-glide parachute, which in calm air travels horizontally two to four feet for every foot it descends and has high maneuverability, provides the promise of increased mobility over those parachutes currently in use by the Army. Its high horizontal speed also overcomes a limitation of the more conventional parachutes by providing a wind penetration capability. These characteristics make the high-glide parachute of interest for certain military operations.

Parachutists involved in specialized operations, such as those employing small combat groups or clandestine teams, could jump from medium or high altitude with a large offset from their intended landing area and thereby achieve better security for the operation. Due to the high horizontal speed and the capability of the jumper to maneuver the canopy he could better cope with the vagaries of the prevailing winds and lessen inaccuracies due to release point errors. A few specific areas of application of this type of parachute would be as a replacement for the present maneuverable parachute for free-fall operations or as the main recovery parachute of a two-stage, stabilized fall, high altitude airdrop system for personnel.

The use of maneuverable, high-glide parachutes during mass troop type static line jumps is questionable due to the congestion in the air over the drop zone and the intensity of training which may be required to achieve and maintain in the paratrooper the high degree of expertise necessary to adequately handle this type of chute. A further consideration would be the adverse impact on already overburdened and understaffed packing and maintenance facilities as a result of the longer turn around time associated with this type of parachute. More frequent and detailed inspections would also be required to insure that no dimensional changes had occurred to upset the desired aerodynamic characteristics of the parachute, and repairs would be of a more complicated and time consuming nature than those associated with currently used personnel airdrop parachutes.

TYPES OF HIGH-GLIDE PARACHUTES

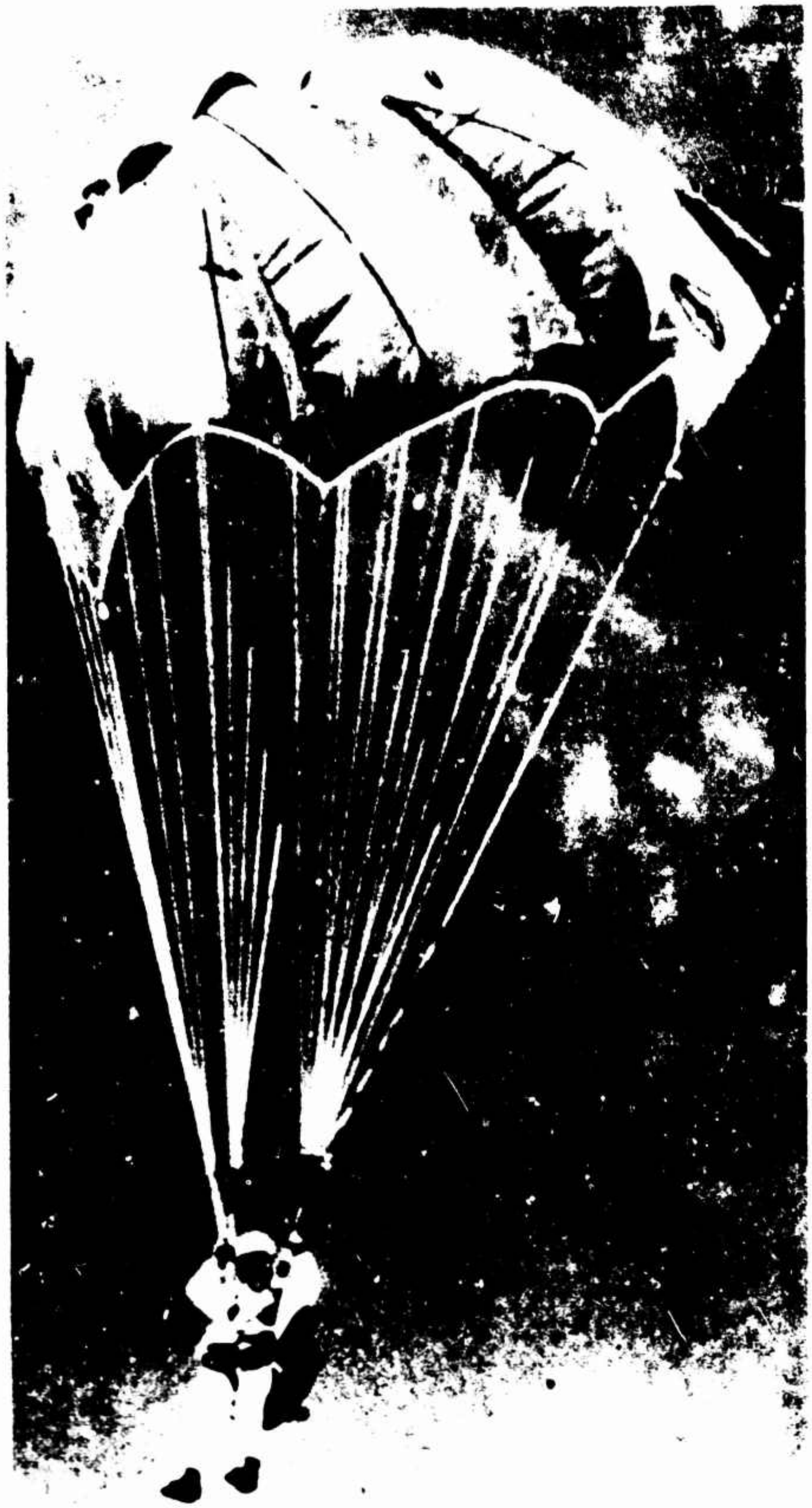
Parawing

The best known and most thoroughly investigated type of gliding parachute is the Parawing. Investigation of Parawing technology has been going on for somewhat more than a decade and is an outgrowth of early work on flexible kites by Mr. Francis M. Rogallo of NASA. During its investigations, NASA has conducted or sponsored studies on over one-hundred variations ultimately focusing their efforts on the single (Fig. 1) and twin-keeled (Fig. 2) Parawing designs. Other investigatory work on the application of the Parawing to precision airdrop of cargo has been conducted by the U. S. Army Aviation Materiel Laboratories and at least one manufacturer is producing a slotted canopy Parawing for sports parachutists. The first premeditated jumps with the Parawing were made in 1966 by members of the U. S. Army Demonstration Team (Golden Knights) and Special Warfare Personnel at Fort Bragg, North Carolina. Many more Parawing jumps have been made in the intervening years by both military exhibition teams and sport parachuting enthusiasts.

The most common configurations of the all-flexible Parawing being employed for personnel jumps at this time are either single or twin-keeled, having leading edges which are swept 45° and equal in length to the theoretical keel length. To forestall premature nose collapse or tuck under, the nose of the Parawing is cut-off at a distance one-eighth of a keel length back from the theoretical leading edge apex.

The Parawing being of all flexible construction, depends on tension in suspension lines located along its leading edges and keel(s) to maintain the proper canopy shape when inflated. Unequal elongation, that is not immediately recoverable, of any of these lines occurring during the opening process causes changes in the inflated canopy shape and aerodynamic performance. The number of lines vary with different designs with control being effected by retraction of the most rearward leading edge suspension line located at each tip. Dependent on their number and function, these suspension lines vary in breaking strength from 550 lbs. to 1500 lbs. Both solid and slotted canopies have found application in personnel use with the canopy material being of zero or very low porosity calendered and coated nylon ripstock weighing 2.25 oz./sq yd. Both


ARMY



bag and sleeve type deployment have been employed, generally in conjunction with some type of opening shock attenuating device.

Much interest has been generated in the basic Parawing because of its relative simplicity, positive and reliable opening characteristics and its capability of maintaining stable gliding flight when properly trimmed. However, the inherent rapid opening characteristics of the unreefed low porosity canopy causes undesirably high opening shocks.

U.S. Navy tests of 20 and 24 ft. unreefed Parawings deployed by static line at 80 to 110 KIAS at 1000 ft. pressure altitude indicated excessively high opening shocks with an attendant suspension line elongation problem.[1] It was concluded that in order to improve deployment and ensuing flight performance, further design and development work was required.

Numerous methods and devices have been employed in an attempt to reduce the high shock loads to a comfortable level for repeated jumps (about 4-6 G's). A reduction in opening shock to this level would also greatly reduce structural problems and result in more consistent aerodynamic performance. The use of a slotted canopy appears to lower the opening shock by about forty percent.[2] Such techniques as staged inflation using various reefing techniques, use of a wrapping flap to slow inflation by releasing the lines slowly, various degrees of nose tuck in conjunction with a zero length reefing line, center keel-line retraction and various mechanical devices have been tried with varying degrees of success. In some instances opening shock loads at fairly high dynamic pressure have been reduced to a comfortable level with a particular attenuating method or device but the means employed proved to lower the reliability of opening, introduce a tendency for the canopy to spiral during some stage of opening or be incapable of producing repeatable results. Conflicting comments from jumpers regarding the severity of opening shock when using current methods of attenuation indicates a lack of consistency and repeatability in the opening shock experienced and the need for further improvements.

Test data indicate the twin-keel Parawing to have a somewhat higher L/D than the single-keel Parawing. Various sources have reported a nominal L/D of approximately 2.0 for the single-keel version versus a nominal L/D for the twin-keeled version of about 2.8. Maximum L/D values attained in wind tunnel tests without the added drag of a payload were 2.7 for the single-keel and 3.3 for the twin-keel. The Parawing shows a direct correlation between

L/D and control input sensitivity. When trimmed for maximum L/D it is quite sensitive to canopy geometry changes caused by either intentional control inputs or unequal line or canopy set. The unintentional inputs oftentimes results in lower lift/drag ratios and dynamic stability problems. Degree of bank, rate and direction of turn depends on retraction of control lines running to each tip. Control line movements of less than 1% of the theoretical keel length will induce a shallow bank and slow turn to the same side as the retracted control line. A retraction of about 5% will result in bank angles on the order of 50-60 degrees and 360° turns in 3-4 seconds. Required control line input force varies from 10-12 lbs. at 1% retraction to 20-25 lbs. at 5% retraction. The angle of attack range over which the canopy is statically stable is quite small and is limited to angles below stall. Maximum L/D occurs at the minimum stable angle of attack and a further reduction of this angle results in canopy nose collapse. Control inputs that take the canopy through stall can cause pitch oscillations and in some cases short periods of vertical or backward flight of the canopy have been observed. Stall recovery is affected quite readily by releasing the control lines to the steady flight configuration.

The resultant force coefficient of the parawing is essentially constant over the stable angle of attack range and therefore, the flight velocity components at a given altitude are fixed by the wing loading. Assuming an L/D of 2.0 for a single-keeled solid Parawing, wing loadings of 0.5 lbs./ft.^{2} to 1.5/ft.^{2} appear to be reasonable for personnel jumps and result in vertical velocities at sea level of about 9 ft/sec to 16 ft/sec respectively with horizontal velocities of 18 ft/sec to 32 ft/sec. Most sport and military demonstration jumps have been made at the lower to mid-range wing loadings resulting in fairly low velocities. These low velocities are entirely adequate for jumps of this type as the jumper does not have to jump on days with high wind conditions. Landing in winds of higher speeds than the still air horizontal speed capability of the canopy, gives the jumper the unenviable choice of landing backwards or making a high speed downwind landing. In flight, a high horizontal speed for good wind penetration is desirable while at landing, low vertical and horizontal velocities are desirable. Various devices or techniques have been employed in an attempt to lower landing velocities to acceptable values. Such methods are employed as orienting the canopy into the wind on landing, flaring out the canopy just before touchdown, and use of a landing flap. Also proposed is the variable area twin-keel Parawing. This design has the keel reefed together to reduce the canopy area, thus increasing velocities during flight. Provision

is made to disreef the keels before landing which increases the area, lowers the wing loading and reduces the horizontal and vertical velocities.

The currently employed landing technique results in a considerable reduction of horizontal and vertical velocity at landing by orienting the canopy into the wind and performing a flare maneuver. This maneuver calls for precise timing and expertise and is executed by starting control line retraction 6-8 ft. above ground so that at touch down the arms are fully extended. Starting a turn to orient the canopy into the wind at too low an altitude or starting the flare maneuver slightly early can result in high impact velocities at landing, with an increased potential for injury.

Para-Foil

The concept of the Para-Foil (Fig. 3) high-glide parachute originated with Mr. Domina C. Jalbert and in its original form was called the "Jalbert Multi-Cell Airfoil." Since 1964 continuing research and development has been carried on by the USAF and the University of Notre Dame under the guidance of Dr. John D. Nicolaides of the University's Department of Aerospace and Mechanical Engineering. During tether tests at Notre Dame in 1965, two students were inadvertently lifted from the ground and thus live Para-Foil flights began. It soon became standard practice to tow students to several hundred feet, release the tow rope and let them glide back to earth.

The first premeditated live jumps took place in 1966, utilizing Para-Foils of 1.5 and 1.8 aspect ratios with 165 and 360 square feet of area respectively. Under the guidance of Dr. Nicolaides of Notre Dame, members of the US Army Golden Knights parachute team successfully jumped a Para-Foil of 2.0 aspect ratio and 360 square feet a total of 30 times. In late 1967, the US Air Force Flight Dynamics Laboratory acquired from Notre Dame a 2.0 aspect ratio Para-Foil of 360 sq ft. area to accumulate live jump performance data. The live jump tests were conducted in June of 1968 and consisted of seven successful jumps from a light aircraft. Visual observation and post-jump comment by jumpers, reported reliable deployment and inflation, good flight performance and easy "flare-out" capability on landing. Since then many more successful jumps have been made by the members of the Golden Knights.

The Para-Foil is rectangular in planform and when inflated it has a double surfaced flat bottom air foil shape of approximately 20% thickness. The upper and lower surfaces are constructed of low or zero porosity coated nylon and it is divided into a number of cells by fabric ribs. These cells are open at the leading edge and closed at the trailing edge. When in flight, ram air pressure inflates these cells through the open leading edge and this in combination with the reduced pressure over the top surface, inflates the Para-Foil to its airfoil shape. The fabric ribs separating the cells are ported to equalize the air pressure throughout the inflated canopy. For all practical purposes, once the canopy is inflated, the ram air within is stagnant and there is no air flow either into or out of it. Suspension lines are attached to the bottom of the canopy by flares or pennants along the rib lines. These flares serve to transmit and distribute

suspension line loads evenly, provide side area for dynamic flight stability and reduce aerodynamic losses at the sides. Suspension lines are of 550 and 750 lbs. breaking strength nylon cord and control is effected by a downward deflection of the outer trailing edge of the canopy on the same side as the intended turn. The landing flare maneuver is performed by an equal, downward deflection of both outer trailing edges.

Various packing and deployment techniques have been used to control the high opening forces that are associated with all low porosity canopies. Available data indicate that unreefed opening forces are somewhat lower than for the unreefed Parawing. US Navy tests of an unreefed Para-Foil for personnel having an area of 360 sq. ft. and an aspect ratio 2.0 resulted in unacceptably high opening forces.(3) Average opening shock load at 150 KIAS and 1500 ft. altitude was 14.0 G's with a peak of 19 G's. A peak of 16 G's was recorded at 131 knots and 15,000 ft. before the canopy suffered major damage such that it did not inflate. Average lift/drag ratios measured varied from 2.6 to 3.8. It was concluded that structural elongations occurring because of the high opening forces resulted in the varying performance and it was necessary to measure and adjust suspension lines prior to each flight.

On cargo drops the Air Force has reduced opening shock on a Para-Foil from about 15 G's at 130 KIAS to approximately 4 G's, which occurs twice during opening. This method incorporates riser reefing and closure of about 30% of the cell inlet height. This is two-stage reefing, the closure of the inlet for two seconds after aircraft release and riser reefing for four seconds. Total reefing time is four seconds. The Para-Foil remains in a partially inflated condition until riser release, whereupon it assumes its unreefed angle of attack and completes inflation. This rapid change in angle causes a pendulum type oscillation which dampens out in about 15 seconds.

As would be expected from airfoil theory, lift/drag ratio varies with aspect ratio. Wind tunnel tests have determined the maximum lift/drag ratio of a canopy with an aspect ratio of 1.0 to be about 3.0 at an angle of attack of 10°, a maximum L/D of 6.0 at 6° angle of attack was measured for a 3.0 aspect ratio canopy. With estimated line drag these figures are reduced to 2.8 at 12° and 4.0 at 8° respectively. In general, actual flight tests have shown somewhat higher lift/drag ratios with a greater dispersion of measured values. The higher values of L/D may be due to the higher Reynolds number and the dispersion due to measuring inaccuracies or flight trim inconsistencies. Ideally, large aspect ratios are desired to obtain high values of lift/drag. However, this is not always possible from a practical standpoint and conservative aspect ratios of around 2.0 are employed for spanwise

rigidity, safe deployment, reasonable efficiency, and flight stability. The average glide ratio during flight is lowered somewhat due to lift/drag reduction during turns and wind gusts. Canopy loading for personnel airdrops would depend upon the wind penetration desired and would vary from about 0.75 to 2.0 lbs/sq ft for probable military applications.

Para-Foil steering control can be effected in several ways. The Air Force investigated steering by warping the trailing edge of the Para-Foil by pulling on various suspension line flares in the aft two rows and also by the method of deflecting one of the forward outboard corners by collapsing or constricting the cell inlets. Pulling on the aft flares sometimes resulted in control reversal, the Para-Foil turning to the side opposite the intended turn and then reversing itself to the intended direction after further control line retraction. Constricting the inlet cells required less control line travel and force and did not exhibit the control reversal characteristic. Evidently the problem of control reversal has been solved as the currently used method of control for manned Para-Foil use is the trailing edge warp. With this type of control, lift is lost on the side of canopy deformed by the pull on the control lines. Therefore, control is by a spoiler effect as opposed to a conventional aileron effect.

The Para-Foil has demonstrated the capability of being flown over a wide range of stable angles of attack from about minus 8° to plus 80° and according to statements from its proponents, the lift/drag ratio can be modulated while in flight from zero to maximum. Tests that have been conducted have shown excellent inflight stability with the capability of the canopy being flared out for landing when 5 - 10 ft. above the ground by simultaneously retracting both control lines to their full extension. When done correctly, this results in a near zero velocity landing.

Because of the double surface airfoil shape, the weight, bulk and complexity of construction of the Para-Foil is considerably greater than the Parawing. Its cost is therefore correspondingly greater also.

Volplane

The "Volplane" (Fig. 4) is a high-glide parachute design of the Pioneer Parachute Co., Manchester, Connecticut. No wind tunnel and only limited flight test data was available to the author from the manufacturer. The "Volplane" is rectangular in planform. It is a semi-double surface canopy and is double surfaced for 50% of its cord length behind the leading edge. The rear of the bottom surface is sewn to the upper surface with a forward folded flap that functions in the manner of a check valve. The double surfaced portion is divided into a number of individual cells similar to the Para-Foil by fabric ribs which contain ports to equalize the air pressure within the canopy. Catenary panels sewn to the canopy to alternate rib positions serve to distribute loads in the suspension lines and to provide side area for increased stability. The patented cell construction results in a check valve type action that prevents the canopy from collapsing by providing a reversed air flow through the cell when the canopy stalls, thus maintaining pressure against the upper surface. The shape of the leading edge is maintained in normal flight by ram air pressure and the rear of the cell is closed against air flow.

It is claimed that the Volplane opens in an orderly manner and when used without reefing has an opening shock similar to a reefed Parawing. Considerable work has been done by the manufacturer in an attempt to produce a reliable reefing device to limit the opening shock at low altitude terminal velocity deployments. The current reefing method being supplied with the canopy consists of a cord that is threaded through grommets in each flare just above the flare/ suspension line attachment points, a trigger release mechanism for effecting disreef. and a hydraulic cylinder which controls time to disreef. Two opening shocks are felt with this system, one at reefed inflation and a second of slightly less magnitude at full inflation. Qualitative descriptions of the opening shocks experienced at terminal velocity deployments with 3-4 second reefing delays, liken them as being about the same as that experienced with a low altitude terminal opening of the Army's standard HALO maneuverable parachute. Excessive reefing delay sometimes results in line twists brought about by canopy rotation. Unequal line stretch problems are claimed to be eliminated due to the low opening shock at the deployment velocities of interest to the sport jumper and by the use of prestretched and heat set Dacron lines.

The Volplane reportedly is not as sensitive to control line movements as a single surface canopy and rate of turn is reported to be on the order of 4-5 seconds for the first 360 degrees. Control is

Figure 4. VOLPLANE

accomplished by deflecting the outer trailing edge down in the intended direction of turn. Stalls can be induced by about a 3 foot retraction of both control lines. During stall the air flow is reversed forcing the cell safety valve open reportedly resulting in short periods of reverse flight.

Periods of extended flight at lift/drag ratios varying from about 0.8 to a maximum of 4.0 are reported. Vertical and horizontal velocities are significantly reduced for landing by performing a flare maneuver.

Sailwing

The "Sailwing" high-glide parachute (Fig. 5) is a design of Mr. David Barrish of Barrish and Associates, New York, New York. It is essentially rectangular in planform consisting of five lobes of shaped panels rolled under at the leading edge. It is a single surface canopy being constructed of calendered and coated 1.6 oz/sq yd low porosity nylon ripstock with catenary panels at the lobe junctions which are shaped to give a slight camber to the canopy. Suspension and control lines are currently of low elongation Dacron of various tensile strengths which are attached to the catenary panels.

The sailwing is deployed in a reefed condition by a pilot chute. Six seconds after line stretch a canopy reefing line is cut allowing the reefed canopy to partially inflate to a horseshoe like shape. Ten seconds after line stretch the control line reefing is cut and the canopy assumes its fully inflated wing-like gliding configuration. Transition from the partially inflated horseshoe stage to the final glide configuration is sometimes random with a tendency for the outboard canopy panels to flap, rotate, and the leading edges sometime fold and tuck under. If this action is severe enough, full inflation will not take place.

In a recent US Navy test opening forces varied from 6.4 G's to 11.5 G's using the aforementioned reefing with static line deployment initiation at speeds of 60 to 110 KIAS at 1500 foot altitude.(4) In eleven out of eighteen tests conducted, a malfunction of one type or another caused the canopy to fail to fully inflate. After each test it was found necessary to replace the control lines because of damage that they had incurred during deployment. Testing was terminated due to the deployment and inflation problems. When the canopy was successfully deployed, it glided in a stable manner with little oscillation and had an average L/D which varied from 0.41 to 5.1. The large variation in L/D being the effect of the various canopy and control line damage. When line stretch does occur, it generally manifests itself in an assymetrical canopy condition inducing a tendency for the canopy to turn to one side or the other. A recent change from nylon to low elongation Dacron has reportedly eliminated problems of line stretch.

Steering and control is done through a left and a right control line attached to a bridle arrangement to deflect the outer trailing edge downward on the side of the intended turn. Control sensitivity is reported to be similar to the Parawing with a somewhat greater force required to effect a turn. Stalls are said to compare in severity with

Figure 5. [illegible]

those of the Parawing. Stall recovery is brought about by release of the control lines and is immediate but there is generally a short period of instability before stable flight is again achieved.

Typical size and loading, claimed by the designer, for a Sailwing intended for personnel use, would be a canopy loading of 1.4 lbs/sq ft and an aspect ratio of about 3 or 4 to 1. It would have a rate of descent on the order of 8 ft/sec with an average lift/drag ratio of 4. The permissible lift/drag modulation is also similar to the Parawing (quite low). The maximum lift/drag ratio of the Sailwing is limited by leading edge collapse. When this occurs large oscillations ensue. Speed reduction at landing is accomplished with an into-the-wind flare maneuver in the same manner as with other high-glide parachutes.

DISCUSSION

The feasibility of the maneuverable high-gliding parachute has been proven. Successful jumps by sports enthusiasts and the US Army Parachute Team (Golden Knights) are now an everyday occurrence. However, these jumps are in most instances made in daylight hours under favorable environmental conditions, by jumpers with a high degree of training and expertise and unencumbered with combat equipment. These highly trained jumpers are generally able to cope with emergency situations such as poor openings or out of trim flight much more readily than the average military paratrooper.

The equipment used by the sport jumper is not normally used at the higher deployment speeds and altitudes and in the environmental extremes involved in airborne operations. Further, it does not have to comply with the reliability standards of the military which must be met to provide safe injury free airdrop of personnel charged with vital military missions to perform. FAA regulations require only one approved parachute to be worn by the sport jumper. This enables him to use a main parachute that hasn't been FAA qualified as long as he wears an FAA approved reserve. The attitude of the more proficient sport jumper, in general, is that if a malfunction occurs it can be readily overcome by utilization of the proper corrective action or the main canopy may be jettisoned and the reserve employed. This is not without its consequences. The past and present safety record achieved with sport parachuting equipment is not acceptable for military premeditated jumping. In those cases where such equipment has been employed by the military because of other overriding considerations, the safety compromises involved have been clearly defined to the user.

Improvements have been made in methods and devices to attenuate loads encountered during the opening process of high-glide parachutes. These methods and devices developed by private industry have been primarily geared toward limiting the degree of opening loads encountered when the canopy is deployed at terminal velocity and low altitudes. However, engineering development still remains to be done in this area to further attenuate opening shock and improve deployment/opening reliability for military use.

All high-glide parachutes are performance sensitive to canopy geometry changes resulting from unrecovered, unequal elongations of the canopy itself or the suspension/control lines. US Navy tests of unreefed high-glide parachutes have revealed a necessity to adjust suspension/control lines to original trim lengths prior to each jump. Failure to do so

resulted in an overall lowering of performance and reliability that would be hazardous to a jumper. Very high opening forces were encountered with these unreefed low porosity canopies even at low deployment airspeeds and altitudes. The use of reefing or staging to limit the peak opening loads is mandatory and provides a partial solution to the structural problems.

Some investigatory work has been done in an attempt to determine materials and methods of construction best suited for high-glide parachute construction.(5) A calendered and polyurethane coated nylon ripstop weighing 2.2 oz/sq yd has been proposed as meeting the criteria for high-glide personnel canopies in that it has a high strength to weight ratio, low porosity after biaxial loading and good resistance to frictional burning. Results with line material have not been as promising, as it was determined that none of the materials tested had the desired dimensional stability. The current approach to the line problem used on some high-glide designs, is the use of prestretched and heat treated dacron. The lines are so sized that tensile loads occurring in the lines during opening shock are well within the elastic limit and any resulting elongation is immediately recovered. It is claimed that this approach in combination with an attenuator to limit peak opening loads, virtually eliminates trim problems due to line stretch at low altitude, terminal velocity deployments. No definitive test data are available to support this claim other than qualitative reports from sport jumpers. As dimensional integrity of the lines after subjection to opening shock loads has been a problem common to all high-glide canopies tested by the military to date, this claim bears close scrutiny.

The parachutes discussed in this report are controlled or steered by a downward deflection of the trailing edge or tip of the canopy on the same side as the intended turn. The flare-out maneuver which reduces horizontal and vertical velocities at landing is performed by a simultaneous equal, downward deflection of both outer trailing edges or tips. The single surface canopy designs have a very narrow range of stable angle of attack with little lift/drag modulation capability. They are also less tolerant of heavy-handed control inputs and structural elongations than the double or semi-double surface canopies. Their main appeal lies in their relatively simple construction and consequent lower cost, weight and volume. The full or semi-double surface canopy designs appear to have an advantage in aerodynamic performance and stability. Test data indicates a range of stable angle of attack roughly three times that of the single surface designs with the capability of much greater lift/drag modulation. Less critical preparation for the landing flare maneuver with greater speed reduction is also claimed for these designs.

All manufacturers of sport type high-glide parachutes currently recommend that a prospective user have a high degree of parachuting expertise, on the order of 200 jumps with a maneuverable parachute of the type used for competition jumping. Some include a mandatory jump orientation training program with the sale of each high-glide chute. In the case of those designs that are towable, control and landing practice can be accomplished using a car or truck to tow the parachute to altitude whereupon the trainee releases the tow and glides in for a landing.

SUMMARY

Although routine jumps are being made every day with gliding parachutes by sport jumpers and military demonstration, exhibition and competition teams, military combat operations require higher performance parameters. Deployments at higher airspeeds and altitudes with no appreciable increase in opening shock loads over that of current standard military parachutes dictates the need for a shock attenuating method or device that does not adversely affect the overall reliability of the opening sequence and subsequent gliding flight. At present there is no proven device or method that has demonstrated this capability.

Aerodynamic performance is such that a high glide parachute when sized to be competitive in weight and packed volume to a standard military maneuverable parachute results in horizontal and vertical velocities of possible military interest for such purposes as wind penetration, offset jump capability, landing in higher ground winds and reducing drop zone dispersion. It should be borne in mind that jumpers of different weights, using the same size and type of canopy, would have different gliding velocities with the heavier jumper being able to penetrate somewhat higher winds.

Testimony of sport jumpers supports the claim of manufacturers that the problem of flight to flight performance changes occasioned by random canopy or line stretch has been eliminated or greatly lessened at the deployment speeds and altitudes of interest to the sport enthusiast This has been brought about by the application of better suited materials and techniques of construction and the use of various techniques to limit opening shock loads. It is possible, however, that undetected subtle, long-term changes in performance might take place.

All the gliding canopies that have been discussed in this report are capable of controllable, stable flight although certain types are inherently more stable and therefore more tolerant of control input excesses. As with any high performance vehicle with increased modes of control, the use of a high-glide parachute requires that the jumper achieve and maintain a higher degree of expertise than that required for current parachutes in use by paratroopers. The exercise of good judgment on the part of the jumper becomes increasingly more important with the high-glide canopy.

Because of the increased mobility it affords, the high-glide parachute warrants consideration for certain types of military personnel airdrop operations. Further development work on current systems for personnel would be required to enable them to be used at the higher deployment speeds and altitudes of probable interest to the military Extensive

testing would be required to establish the reliability of any given system before adoption for military purposes. No reliability data is available for the systems currently being used by sport enthusiasts. It appears that a major functional problem to be solved is the development of a device or method to limit opening shock loads to allowable levels without introducing other problems which affect the reliability of the opening process and subsequent gliding performance.

The use of high-glide parachutes for military operations would require a device that in periods of darkness or limited visibility would enable the jumper(s) to know his position and altitude relative to the intended landing area at all times. A further requirement would be a knowledge of the wind direction at ground level and a means of accurately sensing the last few feet above ground so that the canopy could be oriented into the wind and the landing flare-out timed precisely. Inability to follow this procedure would in all probability result in injury due to excessive landing velocity, which is less tolerable to a paratrooper because of his attached combat equipment. An idealized approach to the problem and one that would require little or no expertise of the jumper would be a completely remote controlled system. This system would require no control inputs by the jumper. All heading and attitude corrections including orientation of the canopy into the wind for flare-out and landing would be made automatically.

Problem areas other than technical that should be considered are the increased logistics demands and the high degree of training probably necessary to achieve and maintain efficiency on the part of the user of this type of parachute. Such training imposes a severe and sometimes unacceptable burden on the unit commander if the user expertise required is achieved only at the expense of other training possibly more important from an overall viewpoint to the satisfactory conduct of assigned combat missions. A highly trained expert jumper, poorly trained and qualified in his primary operations duties, is of questionable value to his unit.

Above all, it must be conclusively shown that high-glide parachutes can be used as safely and reliably as presently employed parachute designs and that they can be employed effectively in the conduct of military airdrop operations. These are areas of extreme controversy between the military planners and user personnel even with the lower performance parachutes in use today for military special mission type operations. There is no present or anticipated military requirement for development of, or support of, high-glide parachutes for demonstration, exhibition or competition jumping.

CONCLUSIONS

It is concluded that:

1. High glide parachutes have a potential for military airdrop operations in the following areas:

(a) Penetrating and landing in high winds.

(b) Reduction of drop zone dispersion.

(c) Lessening landing inaccuracies due to difficulties or errors in determining the computed air release point for an airdrop.

(d) In the event combat or other conditions warrant it, the ability to choose and to glide to an alternate landing site some distance removed from the initially selected site.

(e) Traveling large horizontal distances from medium and high altitudes to improve security by utilizing off-set capabilities.

2. A major problem that remains to be solved is the development of a reliable and repeatable shock attenuating device that would limit opening shock to an acceptable level for personnel. This device would also work to reduce structural problems such as unequal canopy and line stretch that adversely affects aerodynamic performance.

3 The development of a sensing or guidance system is necessary to enable high-glide parachutes to be used at night or during other periods of low visibility. This sensing or guidance system must be capable of guiding or providing guidance to the jumper:

(a) On the flight path to the intended landing site.

(b) To avoid unseen obstacles in the course of flight or while landing.

(c) To orient the canopy into the wind to lessen the horizontal impact velocity at landing.

(d) To sense a precise distance above the ground in order to perform the flare-out maneuver for landing.

4. Unknown meteorological conditions within a few hundred feet of the ground such as extreme turbulence or gusty winds would be very hazardous to a jumper when using this type of parachute.

REFERENCES

1. "Performance Evaluation Tests of 20 and 24 Food Parawings," George L. C. Menard and Mathais N. Ternes, US Navy Aerospace Recovery Facility Tech Rept 8-67, El Centro, Calif. November 1968.

2. "Status of Research on Parawing Lifting Decelerators," William C. Sleeman, Jr. and Thomas G. Gainer, NASA Langley Research Center, Hampton, Virginia, Proceedings Aerodynamic Deceleration Systems Conference 1968, AIAA; FTC Technical Rept No. 69-11, Vol. II, April 1969.

3. "Performance Evaluation Tests Para-Foil Manouverable Personnel Gliding Parachute Assembly-Aspect Ratio 2-Area: 360 Square Feet," Tech Rept No. 2-69, Final Rept September 1969, George L. C. Menard, US Naval Aerospace Recovery Facility, El Centro, California.

4. "Performance Evaluation Tests of Sailwing, Maneuverable, Personnel, Gliding Parachute Assembly," George L. C. Menard, US Navy Aerospace Recovery Facility, Technical Note 1005-70, El Centro, California, June 1970.

5. "An Investigation of Low Permeability Fabrics and of Suspension and Control Lines for the All-Flexible Parawing," R. V. Lashbrook and C. M. Mabry, Ventura Division of Northrop Corporation, Newbury Park, California, Proceedings Aerodynamic Deceleration Systems Conference 1968, AIAA; FTC Technical Rept No. 69-11, Vol. II April 1969.

BIBLIOGRAPHY

"Theoretical Aerodynamics of Flexible Wings at Low Speed V-Engineering Method for Estimating Parawing Performance," J. N. Nielsen, VIDYA Division, Itek Corporation, Palo Alto, California, AD 628-579, December 1, 1965.

Progress Report, 20 May 1970--Engineering Test of 500-lb. Controlled Airdrop Cargo System (Parawing), USATECOM No. 4-ES-065-001-004, 20 May 1970.

"Review of Methods for Predicting the Aerodynamic Characteristics of Parawings," Michael R. Mendenall, Shelden B. Spangler, and Jack N. Neilsen, Nielsen Engineering & Research, Inc., Palo Alto, California, J. Aircraft Vol. 5, No. 6, November-December 1968.

"Live Testing of Various Gliding Devices," Edwin D. Vickery, Pioneer Parachute Company, Inc., Manchester, Connecticut, Proceedings Aerodynamic Deceleration Systems Conference 1968; AIAA; FTC Technical Rept No. 69-11, Vol. 1, April 1969.

"Parawing Precision Aerial Delivery System," J. Everette Forehand, US Army Aviation Material Laboratories, Fort Eustis, Virginia, and Herbert Q. Bair, Goodyear Aerospace Corporation, Akron, Ohio, Journal of Aircraft, Vol. 6, No. 5, September - October 1969.

"Individual Flight," John W. Sobczak, US Army Aviation Material Laboratories, Inter-Agency Flexible Wing Technology Meeting, Langley Research Center, Hampton, Virginia, June 6 and 7, 1967.

"Configuration Studies of All-Flexible Wings Conducted at the Langley Research Center," Wiliam C. Sleeman, Jr., Langley Research Center, Hampton, Virginia, Inter-Agency Flexible Wing Technology Meeting, Langley Research Center, Hampton, Virginia, June 6 and 7, 1967.

"Gliding Parachute Work at Ames Research Center," Kenneth W. Mort, NASA Ames Research Center, Moffet Field, California, Inter-Agency Flexible Wing Technology Meeting, Langley Research Center, Hampton, Virginia, June 6 and 7, 1967.

"Reefing Tests of a 5-Foot (1.524 Meter) All-Flexible Parawing," Charles E. Libbey, NASA, Inter-Agency Flexible Wing Technology Meeting, Langley Research Center, Hampton, Virginia, June 6 and 7, 1967.

"Some Structural Considerations in Flexible Wing Design," Harvey G. McComb, Jr., Langley Research Center, Hampton, Virginia, Inter-Agency Flexible Wing Technology Meeting, Langley Research Center, Hampton, Virginia, June 6 and 7, 1967.

"Glide Performance of Advanced Parawings," William C. Sleeman, Jr., NASA Langley Research Center, Hampton, Virginia, AIAA Paper No. 70-1186, September 1970 American Institute of Aeronautics and Astronautics, New York, New York.

"Parawing Technology for Spacecraft Land Landing, A Progress Report," J. H. Moeller and E. M. Linhart, Ventura/Northrop Corporation, Newbury Park, California, AIAA Paper No. 70-1187, September 1970, American Institute of Aeronautics and Astronautics, New York, New York.

"Theoretical Investigation of the Aerodynamic Characteristics of All-Flexible Parawings," S. B. Spangler and J. N. Nielsen, Nielsen Engineering and Research, Incorporated, Mountain View, California, AIAA Paper No. 70-1188, September 1970, American Institute of Aeronautics and Astronautics, New York, New York.

"Controlled Recovery of Payloads at Large Glide Distances, Using the Para-Foil," C. F. Knapp, University of Notre Dame, Notre Dame, Indiana and W. R. Barton, Saudia Laboratory, Albuquerque, New Mexico, Journal of Aircraft, March-April 1968.

"A Review of Para-Foil Programs," J. D. Nicolaides, University of Notre Dame, R. J. Speelmen III, US Air Force Flight Dynamics Laboratory, and G. L. Menard, US Naval Aerospace Recovery Facility, Paper presented at AIAA 2nd Aerodynamic Deceleration Systems Conference at El Centro, California, 23-25 September 1968.

"Parafoil Flight Performance," John D. Nicolaides and Michael A. Tragarz, University of Notre Dame, Notre Dame, Indiana, AIAA Paper No. 70-1190, September 1970, American Institute of Aeronautics and Astronautics, New York, New York.

"Static and Dynamic Longitudinal Stability of Semi-Rigid Parafoil," R. Harley Walker, Jr., Air Force Flight Dynamics Laboratory, Wright Patterson Air Force Base, Ohio, AIAA Paper 70-1191, September 1970.

"Several Reefing Techniques for Various Gliding Devices," Edwin D. Vickery, Pioneer Parachute Company, Manchester, Connecticut, AIAA Paper No. 70-1192, September 1970, American Institute of Aeronautics and Astronautics, New York. New York.

"Hi-Glide Personnel Canopies: Efforts Toward Identification of Requirements," Ralph J. Speelman III, AFFDL, Wright Patterson AFB, Ohio, Charles Bradshaw, NASA Langley Research Center, Hampton, Virginia, John Sobczak, US Army Aviation Material Laboratory, Fort Eustis, Virginia, George L. C. Menard, Naval Aerospace Recovery Facility, El Centro, California, AIAA Paper No. 70-1194, September 1970, American Institute of Aeronautics and Astronautics, New York, New York.

"Flexible-Wing Testing Techniques And Instrumentation," James L. Hassell, Jr., Langley Research Center, Hampton, Virginia, Inter-Agency Flexible Wing Technology Meeting, Langley Research Center, Hampton, Va., June 6 & 7, 1967.